MISSION PLANNING FOR SPACE-BASED SATELLITE SURVEILLANCE EXPERIMENTS WITH THE MSX

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Abstract - The Midcourse Space Experiment is a BMDO-sponsored scientific satellite set for launch within the year. The satellite will collect phenomenology data on missile targets, plumes, earth limb backgrounds and deep space backgrounds in the LWIR, visible and ultra-violet spectral bands. It will also conduct functional demonstrations for space-based space surveillance. The Space-Based Visible sensor, built by Lincoln Laboratory, Massachusetts Institute of Technology, is the primary sensor on board the MSX for demonstration of space surveillance. The SBV Processing, Operations and Control Center (SPOCC) is the mission planning and commanding center for all space surveillance experiments using the SBV and other MSX instruments. The guiding principle in the SPOCC Mission Planning System was that all routine functions be automated. Manual analyst input should be minimal. Major concepts are: (1) A high level language, called SLED, for user interface to the system; (2) A group of independent software processes which would generally be run in a pipe- line mode for experiment commanding but can be run independently for analyst assessment; (3) An integrated experiment cost computation function that permits assessment of the feasibility of the experiment. This paper will report on the design, implementation and testing of the Mission Planning System.

1.0. INTRODUCTION

The Mid-Course Space Experiment consists of a set of payloads on a satellite being designed and built under the sponsorship of Ballistic Missile Defense Organization (formerly, Strategic Defense Initiative Organization) of the Department of Defense. The major instruments are a set of long-wave infra red sensors being built by Utah State University, a set of sensors operating in the visible wavelength and ultraviolet wavelengths, being built by Johns Hopkins University's Applied Physics Laboratory, and a visible wavelength sensor designed and built by Lincoln Laboratory, Massachusetts Institute of Technology. The satellite bus is being built by JHU/APL who is also acting as the integrator for all the payloads and associated systems. The MSX satellite, shown in Figure 1, is due for launch in late 94 from the Vandenberg launch complex into a near-sun-synchronous orbit.

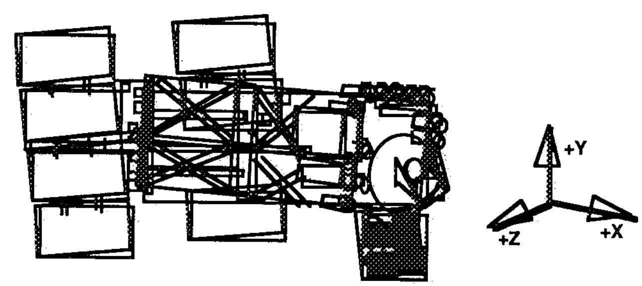

Fig. 1. MSX spacecraft

1.1. MSX Missions and Operations

The MSX satellite is being launched to conduct a series of measurements on phenomenology of backgrounds, missile targets, plumes and resident space objects (RSOs); and to engage in functional demonstrations of detection, acquisition and tracking for ballistic missile defense and space-based space (satellite) surveillance missions.

Eight Principal Investigators are associated with the MSX project. The PIs develop experiment plans that are then prioritized by the BMDO's Mission Planning Team. JHU/APL's Mission Operations Center commands the MSX to carry out the experiments and collect science data. The data are returned to the PIs for analysis and for refining the experiments.

1.2. SBV Processing, Operations and Control Center (SPOCC)

The SBV Processing, Operations and Control Center, located at Lincoln Laboratory, MIT is a component of the APL's Mission Operations Center. In this role, SPOCC (Ref. 1) generates the necessary commanding for the MSX and its sensors for all space-based space surveillance experiments defined by the PI for Surveillance; and converts and calibrates the returned science data before turning them over the SPI's Surveillance Data Analysis Center. Further, SPOCC maintains the health and status of the Lincoln Laboratory's SBV sensor on board the MSX. The software architecture of SPOCC and its interaction with the MSX are shown in Figure 2.

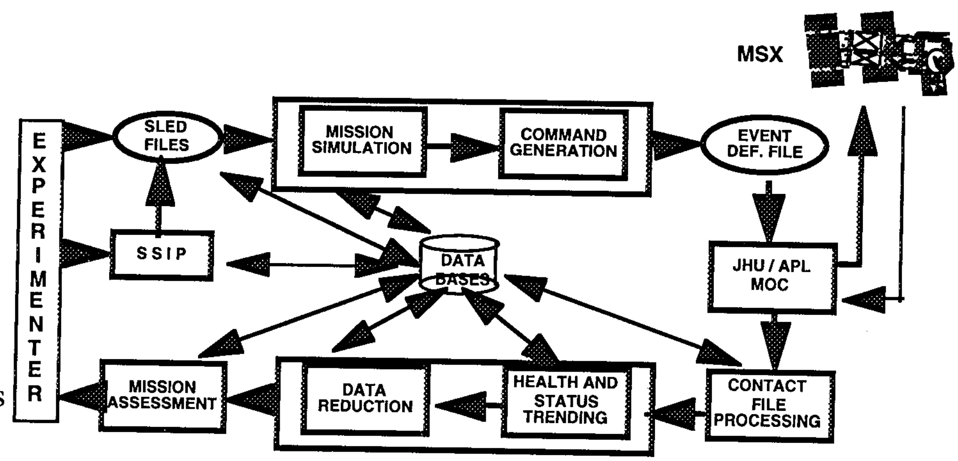

Fig. 2 : SPOCC Software System Architecture

SPOCC has four major functions:

1. SPOCC provides the facility for translating the Surveillance PI's experiments into feasible data collection events on the MSX. The Mission Planning System was designed for this purpose;
2. SPOCC monitors the health and status of the SBV using returned telemetry from the spacecraft;
3. SPOCC provides the capability to decommutate and reduce, to engineering units, the science data collected by the SBV in support of experiments; and
4. SPOCC, in association with the SBV brassboard, provides the facilities to alter, and test, software on-board the SBV in response to changing requirements.

This paper will describe the first part of SPOCC - the Mission Planning System.

The Mission Planning System in SPOCC was originally conceived and designed to support the detailed commanding of the SBV sensor on the MSX. However, because of changing requirements, it has expanded to encompass the commanding of the SPIRIT 3 and UVISI sensors also in support of surveillance experiments. This paper will describe the original design; and use the other sensors as an example of its (limited) adaptability.

1.3. SBV Hardware and Software

A working knowledge of the SBV hardware and software (Ref. 2-4) is essential to understand the design choices made in the Mission Planning System.

The SBV contains of an off-axis imaging telescope with an aperture of 15 cm and a CCD camera at the focal plane. The design improves the off-axis light rejection capability of the telescope over conventional on-axis designs and thus enables the SBV to point within 100 Km of the earth limb without saturation of the focal plane. The camera consists of four CCD arrays each

420x420 pixels, laid out along the Z-axis of the spacecraft. The instantaneous field-of-view at each focal plane is 1.4 deg x 1.4 deg. Distortion due to the off-axis design causes the total instantaneous FOV to be ~6.6 deg. x 1.4 deg.

The SBV carries a redundant pair of Signal Processors whose function is to detect moving targets in a stationary background. The Signal Processor (Ref. 3) collects a set of raw camera frame data (4 - 16 frames) and applies a space-time filtering algorithm on these data. If the telescope is pointed in an inertially invariant direction, the stars would be stationary and the Signal Processor will detect streaks corresponding to any resident space object in the field-of-view of a CCD array. If, on the other hand, a RSO is being tracked, its image would appear stationary and the stars would generate streaks. Only one focal plane array can be processed at a time. Typically, the SP takes a total time of 50 seconds from the initiation of the frame integration on the camera focal plane to writing out the results of star and streak detection. The algorithm can be controlled to produce a small number of stars for positional reference and a limited number of RSO streaks. A data compression of 10^5 - 10^6 is achieved by the SP.

The entire operation of the SBV is internally controlled by an Experiment Controller. Timed commands are stored in the EC and sent to the various components. Another major function of the EC is to store the results from the Signal Processor in its memory until such time as a downlink event can be initiated.

The SBV has been designed for space-based surveillance of RSOs. The large field-of-view enables rapid search. The off-axis design enables low and high altitude RSOs to be detected and tracked near the earth limb, near the moon and within 25 deg of the sun without saturation of the focal planes. The Signal Processor design optimizes the detection of RSO streaks against a stationary background. The data compression, and the collection of positional data on stars and streaks, permits positional accuracies of the order of a third of a pixel (4 arcsec) which is adequate to support the current requirements of space surveillance. Use of internal memory to store the results and downlinking of the data on demand to a ground station enables the SBV to avoid using the on-board power-hungry tape recorder for storage of data. Further, as in many low altitude experimental satellites, real-time communication is not available and the on-board storage of processed results enables the effective use of limited downlink opportunities.

1.4. MSX Spacecraft

A working knowledge of the MSX spacecraft (Ref. 5) and its capabilities and limitations is necessary to understand the design of and the design choices made in the SPOCC mission planning system. The instruments of concern to the Surveillance PI are the SPIRIT 3 radiometer and the UVISI imagers and spectrometers, apart from the SBV.

The MSX (Figure 1) is a large satellite with all major sensors coaligned rigidly along the X-axis. Thus re-pointing any sensor is equivalent to reorienting the entire spacecraft.

The MSX is severely resource limited (Ref. 6). Power is generated by two solar panels. If all the instruments are on and the MSX is tracking a target, the power demand is greater than what can be generated by the solar panels even at full illumination. The excess demand is serviced from rechargeable Nickel-Hydride batteries. Further, the MSX is in a near-sun-synchronous orbit, and as a result, there are extended shadow periods (up to 20 minutes long in an orbital period of 103 minutes).

The data storage capability of the MSX is limited. Only one tape recorder can be used at a time, and the total data that can be stored is ~36 minutes of data at 25 Mb/s; and 180 minutes of

data at 5 Mb/s. These data can be relayed down to only the APL ground station. It takes 2-3 passes over the APL ground station to read out all the data on a tape recorder of data.

The MSX has severe geometrical constraints (Ref. 6). The most significant of these is levied by SPIRIT 3 sensor which is cryogenically cooled by solid hydrogen. Thermal input into the sensor from the earth and the sun must be minimized to conserve the depletion of the cryogen and prolong the life of the sensor. This necessitates pointing constraints on the +X-axis and the –Y-axis of the spacecraft. The other sensors have pointing restrictions along the +X-axis also.

2.0 SPOCC MISSION PLANNING SYSTEM

The Mission Planning System has the following requirements:

1) Command the MSX spacecraft for all surveillance experiments correctly;
2) Command the SBV in all its operational modes correctly;
3) Command SPIRIT 3 and UVISI in a restricted set of operational modes correctly in support of Surveillance experiments;
4) Monitor constraints and resource usage;
5) Provide a high level language interface to the experimenter;
6) Ensure that modes of operation that are incompatible with the health, safety or operational philosophy of the instruments or the spacecraft are precluded; and
7) Provide a pipelined operational capability in support of rapid and automated generation of commanding for experiments.

The components of the Mission Planning System are shown in Figure 3.

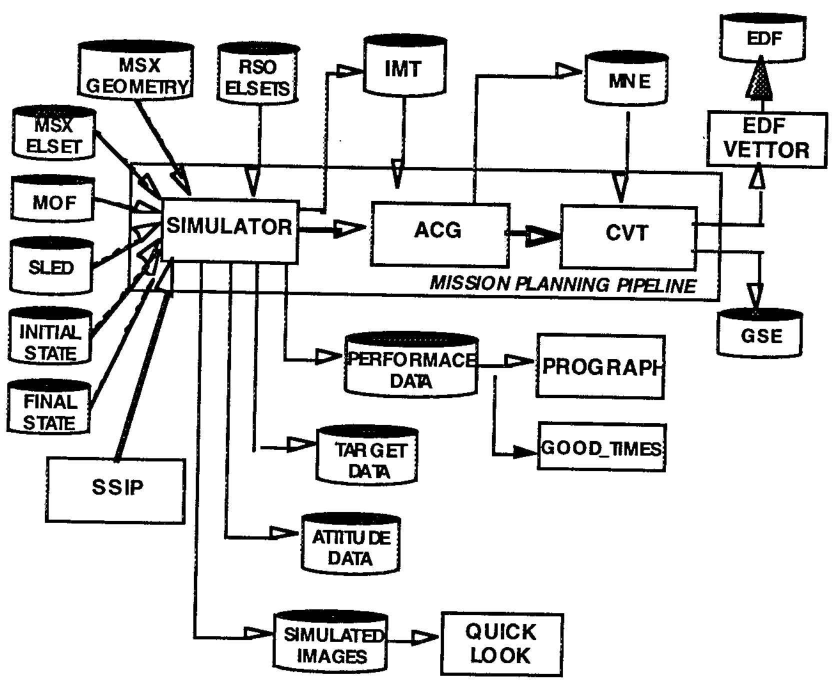

Fig. 3 : Mission Planning System

3.0. THE SIMULATOR

The Simulator is the heart of the mission planning pipeline. It simulates the functioning of the SBV and the MSX and produces the data necessary to both command the spacecraft and to analyze the experiments.

3.1. Architecture

The Simulator is driven by SLED files, either manually created or automatically generated by a component called SSIP(see below). The Parser interprets the SLED code and produces a time ordered, parameterized queue of events to be simulated along with a set of associated data tables. The Simulator takes each SLED generated event and decomposes it into a series of simulation events. Each simulation event corresponds to a state change in the simulation, a change in the attitude control system or a new set of spacecraft or sensor commands. These events are in turn used to drive a standard discrete time simulation. Several graphical, textual and data base/file outputs are produced for analysts to examine and also for further processing by the rest of the Mission Planning System.

The primary sensor for the Simulator is the SBV. Hence, there is a detailed model of all the permitted operating modes and timelines of that sensor. The distributed nature of commanding of the MSX has necessitated an agreement with APL that **all** surveillance experiments will command the SBV regardless of any other sensor used. Thus, the timeline of the commanding for any experiment is primarily driven by the SBV. The SPIRIT 3 and UVISI sensors, when invoked, are used in a restricted set of modes tailored to fit within the constraints of the SBV timing.

3.2. SLED and the Parser

SLED is a high level language used to define an experiment for the mission planning pipeline (Ref. 7). The major concepts in the SLED language are:

1. It is a high level language which permits a description of the experiment.
2. It frees the user from the details of the commanding of the sensors.
3. It frees the user from worrying about detailed timing of the sensor commanding or the experiment operation.

SLED allows a user to describe an entire experiment and simulation in a compact format. The logical structure of the language is shown in Figure 4. The SLED parser, which is the front end of the simulator, takes a SLED input file and produces a set of data structures used to drive the simulation. More importantly, the parser has extensive error checking functions which prevent inappropriate sensor and infeasible spacecraft events from being generated.

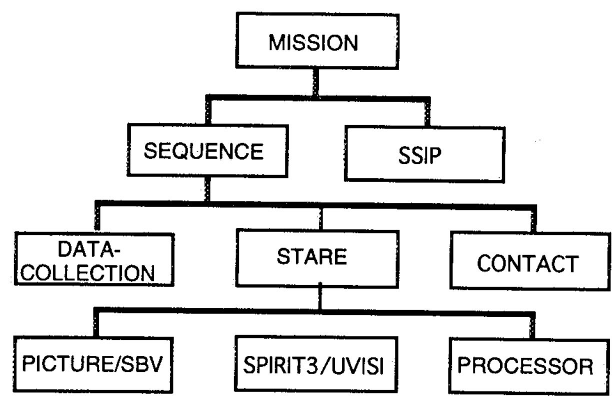

FIG. 4 : Logical Structure of SLED

3.3. Models

3.3.1. Orbital Mechanics

ORBLIB, a set of routines developed at Lincoln Laboratory, is used to determine the position of the MSX, resident space objects, the moon and the sun. The simulator is also able to accept ephemeris files for the MSX produced by JHU/APL.

3.3.2. Attitude Control System

The attitude control system is modeled using software developed at APL. It is essentially the same as the system on the spacecraft with mechanical inputs and outputs modeled in software. It takes as input a set of files corresponding to spacecraft commands and uploadable parameters

and produces an attitude history. Optionally, the operator can select a very simple model, which ignores spacecraft dynamics, for quick look and opportunity analysis.

3.3.3. Power/Thermal Systems

There is a detailed model of the power system which was also developed at APL. It includes modeling of the solar panels, batteries and power electronics. Again, there is a simpler model available for quicklook analyses.

APL has also developed a detailed nodal analysis of the spacecraft's critical temperatures. It models the effects of solar radiation and internal power consumption. In particular, it calculates the temperature of the battery and solar cells which are used as input to the power model. At present it is not implemented and much simpler assumptions are being used (i. e. constant battery temperature). Both the power and the thermal models ignore transients.

GRC, under contract to APL, has developed a model for the thermal behavior of the SPIRIT 3 sensor cryogen. The model takes as inputs the relative position of the sun and earth, the operating mode of the SPIRIT 3 and the temperatures of the baffle, shell and sunshade. It tracks aperture heat load, baffle temperature and cryogen usage.

3.3.4 Contact Scheduling

The MSX is a low altitude satellite that must download data stored onboard during short contacts with fixed ground stations (on the order of 10 minutes). While the downloading of tape recorded data is scheduled by APL, the downloading data stored in SBV RAM is scheduled by the Simulator. During a typical surveillance experiment, or data collection event (DCE), the onboard SBV RAM may be filled and downloaded several times, requiring several contacts.

The mission planning process is an iterative one. Well in advance of running a DCE on the MSX, the Simulator is run to determine what opportunities exist for a particular experiment. APL selects the ones that fit in with the other DCEs being scheduled for other PI teams and sends SPOCC schedule files that reflect when DCEs will run. For each scheduled DCE, the simulator is run to determine how much data is collected in the SBV RAM during the course of the experiment and thereby how many contacts are required. A request for contacts is then made through APL. APL responds with contact scheduling information. The list of contacts, combined with the DCE schedule, is used by the simulator to plan the final DCEs which is run on the spacecraft. The Simulator contains logic to pause data collection during contacts, and maneuver the spacecraft as necessary for contacts over the APL ground station which require a specific attitude.

3.4. SSIP

An operational space surveillance sensor must be able to respond to tasking from the controlling agency by automatically scheduling the tasks in a sensible, prioritized order taking into account visibility, detectability, sensitivity, dynamics, etc. The Space Surveillance Interface Processor provides an automated capability to generate such a schedule - an ordered list of searches for or tracks of RSOs - internally to the Simulator. No on-board capability is being implemented. Instead a ground-based Interface Processor will demonstrate the operational capability.

At present, there are two schedulers, one for geosynchronous searches and one for tasking experiments. The structure of the software allows for the addition of more scheduling algorithms.

SSIP takes a tasking file as input and produces SLED files which are in turn used by the simulator. The tasking file allows the user to specify a complicated scheduling scenario in a very compact format.

There are two concepts of interest in SSIP, pseudo-objects and the figure of merit (FOM). Pseudo-objects are used to produce search spaces. For instance, to search along the geosynchronous belt a set of pseudo-objects would be generated. Each object would have a mean anomaly approximately one field of view apart. As SSIP generates a search for each object, the search space is covered. The FOM is a computed scalar used to determine which object should be tracked next. It is calculated by multiplying a series of weighting factors. These factors pertain to the geometry and dynamics of the orbits of the RSOs, the reflectivity-area product of the RSOs and the characteristics of the background against which the RSOs are detected.

3.5. Outputs

3.5.1. Instantiated Mission Timeline

The instantiated mission timeline or IMT file is a time ordered, time-tagged list of the events that occurred during the simulation. The IMT file is passed on to the ACG/CVT where it is translated into spacecraft commands. It is an ASCII text file which can also be examined by the operator to see the results of a simulation.

3.5.2. The PLOT and Attitude Files

A data file containing the details of the simulation is also produced. The data includes constraint angles, power and thermal data, target information and ground station information. This in turn can be used by the PROGRAPH and Good_times processors of the Opportunity/Feasibility Analysis System (Ref. 8).

The attitude data file contains a detailed listing of the position and attitude of the spacecraft, the status of the SBV (i. e. CCD number, gain etc.) and target data. It is also a operator readable ASCII text file. In addition the attitude file can be used to produce simulated SBV imagery.

3.5.3. Cost Reports

The simulator also produces a compact listing of resource usage data of most interest to an analyst. These data includes power/thermal values, avoidance angles and timing information. These costs are validated by comparing with the more detailed models used by APL.

4.0 COMMAND GENERATION

The Simulator, as described above, generates an Integrate Mission Timeline (IMT) file. The IMT file contains a sequence of spacecraft and sensor commanding events. The Automatic Command Generator (ACG) and Command Vettor & Translator (CVT) complete the mission planning process by converting the high level event description in the IMT file to the SBV and MSX commands that will accomplish the specified events.

4.1 Automatic Command Generator (ACG)

The ACG expands each event in the IMT into a sequence of mnemonic commands. The ACG parses the IMT file, building an event queue from the sequence of spacecraft and sensor commanding events. Each event is processed sequentially, and is converted into one or more mnemonic commands. Each mnemonic represents either a 32 bit SBV serial command, or an APL command packet for an MSX subsystem or another sensor such as the SPIRIT III. The mnemonic commands are written out to an MNE file, short for mnemonics. The mnemonic commands are an intermediate level of commanding designed to be easier to read than 32 bit hex commands and is used primarily for debugging purposes. The mnemonic commands can also be used for writing SBV contingency scripts that do not require simulation of the spacecraft and other sensors.

4.2 Command Vettor & Translator (CVT)

The CVT translates the MNE file mnemonics into the commands that will be transmitted to APL for commanding the MSX and its sensors. The CVT vets and translates each SBV mnemonic into its corresponding 32 bit serial command value. The CVT translates each APL command packet mnemonic into the sequence of APL command domain identifiers corresponding to the command packet for that spacecraft subsystem or sensor. The 32 bit commands and domain identifiers are output to the Event Definition Format (EDF) file which is then transmitted to APL. The Mission Operations Center at APL processes the EDF file, converts the domain identifiers into 32 bit serial commands and builds a command upload for the MSX spacecraft.

The CVT also generates a second output file named the REQ file. The REQ file is used for testing the experiment's SBV commands on the SBV brassboard. The REQ file contains the same 32 bit SBV commands as the EDF file, but the MSX command domain identifiers are replaced by commands to the brassboard's ground support equipment (GSE). As the SBV commands execute on the brassboard, the GSE simulates the MSX spacecraft subsystems that interface with the SBV.

5.0. DATABASES

During a Simulator run, several types of data are retrieved from various databases. A Master Object File (MOF) database provides information on resident space objects. A second database provides schedule information regarding which data collection events are to run when. Information regarding the contact schedule for data downloads is also present in a third database. Both of these databases are used for planning DCEs to take advantage of the ground station contacts available for downloading collected data.

6.0 PIPELINE AND AUTOMATION

The Simulator, ACG, and CVT constitute the core of the SPOCC Mission Planning System pipeline that is run end to end for each data collection event to be run on the MSX. The SPOCC Mission Planning System incorporates several types of automation to minimize human operator workload during mission planning (Figure 5).

The event schedule and contact schedule information arrives from APL as various files which are automatically processed upon receipt, archived, and the appropriate data entered into the databases. Several other files needed for mission planning, such as orbital geometry files, also arrive from APL and are automatically processed and archived.

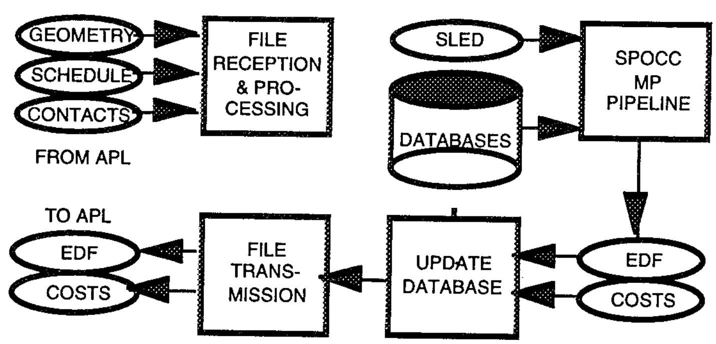

Fig. 5: Automation of SPOCC Mission Planning Pipeline

The pieces of the pipeline can be run either individually, or the whole pipeline can be run with one call to a script. A script is also available to assist the mission planners in properly naming SLED files, as well as one which automatically archives the pipeline output files, transmits the EDF and cost report files to APL, and updates a database as to what files where sent.

7.0 TESTING

Several levels of testing are used to ensure to correct operation of the pipeline during its development. As new features and capabilities are added, developmental unit testing on the individual pieces of the pipeline are carried out. With each major release of the whole pipeline, a series of standard regression tests are run to verify the new release.

As each new type of data collection event is developed, its REQ file is first run through the SBV brassboard to verify that the SBV portion of the commanding is correct. The EDF is then sent to APL for feasibility testing with their MSX spacecraft simulation. Several types of surveillance data collection events have also been run on the MSX spacecraft hardware itself during ground testing as part of the MSX integration and testing effort.

8.0 SUMMARY

A capable mission planning system has been designed and built for space surveillance experiments with the MSX satellite. While primarily designed for experiments with the SBV sensor built by MIT/LL, the system has been expanded to accommodate other sensors on board and also the commanding of the MSX itself. The entire system is designed to be driven by an experiment description in a high level language and a set of data bases. The system can be operated in a pipelined fashion. Comprehensive unit, subsystem and system testing is accomplished with specially designed regression tests. This is followed by validation through a brassboard of the SBV and the spacecraft simulator. The system will be operational at launch of the spacecraft, expected at the end of 1994.

9.0 REFERENCES

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